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Article

Oxidative/antioxidative status in patients after myocardial infarction and in those without cardiovascular event depending on anthropometric factors associated with overweight and obesity

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Abstract: Obesity is one of the factors leading to the development of atherosclerosis. This metabolic disorder is associated with an increased production of reactive oxygen species, which affect the oxidative stress level. The aim of this study was to evaluate oxidative/antioxidative status and to investigate the correlation between redox markers and anthropometric parameters and body composition in adult patients after myocardial infarction and in individuals without a cardiovascular event in the past. Descriptive data on socio-demographic, clinical, and anthropometric features and blood samples were collected and categorized into two equal groups: after myocardial infarction (study group (SG), n = 80) and without a cardiovascular event (control group (CG), n = 80). The oxidative/antioxidative status was assessed in plasma on the basis of total oxidative/capacitive status (PerOx), total antioxidative status/capacity (ImAnOx), and oxidized low-density lipoprotein (oxLDL). OxLDL was significantly higher in the CG group compared to the SG group (p = 0.02). No significant differences were found with regard to PerOx and ImAnOx values between the studied groups. Significant positive correlation between PerOx and percentage of adipose tissue (FM [%]) and body adiposity index (BAI) was found in the two studied groups. ImAnOx significantly positively correlated with VAI in SG and FM% in CG. OxLDL negatively correlated with body mass index and waist to hip circumference ratio in CG. The total oxidative/antioxidative status is related to the amount of adipose tissue and the BAI of the subjects. It was observed that it correlates more frequently with the visceral distribution of body fat.

Keywords: oxidative status; antioxidant status; oxidative stress; cardiovascular diseases; overweight, obesity

1. Introduction

Cardiovascular diseases (CVDs) constitute a major health problem worldwide, and reducing mortality due to these diseases and their consequences is one of the important priorities for health care industries in the developed countries [1]. Atherosclerosis underlies most CVDs and is a disease

that is characterized by multifactorial etiopathogenesis [2]. The origin and course of atherosclerosis is strongly influenced by oxidative stress in the blood vessel wall, which is defined as an imbalance between the production of reactive oxygen species (ROS) in cells and the antioxidant capacity of the organism [3]. Oxidative stress is responsible for causing oxidative damage to lipids, proteins, and nucleic acids as well as results in the modification of their structures and functional properties [4,5]. ROS include small and highly reactive compounds such as free radicals containing an unpaired electron, i.e., a peroxide anion (O2.-) and hydroxyl radical (OH.), and hydrogen peroxide (H2O2), which is not a free radical. Physiologically, ROS participate in many important cellular processes such as growth, proliferation, differentiation, apoptosis, gene expression regulation, protein phosphorylation, and immune defense mechanisms. However, in case of oxidative/antioxidative balance disorders, ROS is produced in excess and contribute to many pathological processes involved in the formation and progression of atherosclerosis. There are three types of ROS activities. Oxidative stress induces strong oxidation and causes damage to proteins, lipids, phospholipids, cell membranes, and DNA, thus contributing to cell dysfunction and destruction. ROS produced in excess react with nitric oxide (NO), which impairs the bioavailability of NO and thus weakens the vasodilatation function of the endothelium. Moreover, ROS modulate the activity of many cellular proteins and signal pathways (redox signaling), thus inducing specific acute or chronic changes in the phenotype and functioning of the cells [6]. The sources of ROS in the cell include: respiratory chain, xanthine oxidase, uncoupled endothelial NO synthase, cyclooxygenase, myeloperoxidase, or lipoxidase [7]. Among these sources, enzymes belonging to the NADPH oxidase family seem to be the key enzymes responsible for ROS production in the cells of vascular walls [6]. Many studies demonstrated that oxidative stress is associated with CVDs and that many atherosclerosis risk factors influence the level of oxidative stress [8–10].

Obesity, i.e., an excessive accumulation of adipose tissue, is considered to be one of the CVD risk factors and at the same time a factor influencing oxidative stress level [11,12]. Adipose tissue, the organ that affects energy homeostasis of the organism, is mainly composed of adipocytes and other cells (e.g., fibroblasts, fibroblastic pre-adipocytes, and endothelial and immune cells) that secrete hormones and cytokines (adipokines or adipocytokines), which subsequently exert endocrine, paracrine, and autocrine effects in the organism. Production of excess energy results in energy accumulation in adipocytes, hypertrophy of adipose tissue, and its hyperplasia. Obesity alters metabolic and endocrine functions of adipose tissue and leads to increased release of hormones, fatty acids, and proinflammatory molecules that contribute to obesity-related complications [13]. In physiological states, and even more so in pathological ones, adipokines induce ROS production, affecting oxidative stress formation. Several mechanisms are involved in the development of oxidative stress in obese individuals, and the mechanisms related to oxidative stress formation are strongly associated with pro-inflammatory processes that cause endothelial damage and excessive formation of free radicals. The presence of excessive adipose tissue was found to be a source of pro-inflammatory cytokines, including tumor necrosis factor alpha, interleukin (IL)-1β and IL-6 [14], C-reactive protein, leptin, and resistin [15].

The formation of ROS and NO is an inseparable phenomenon accompanying biochemical changes occurring in the human body, which under hemostasis conditions has developed mechanisms to protect biomolecules against harmful effects of free radicals. Protective functions are performed by enzymes like peroxide dismutase, catalase, and glutathione peroxidase; water; fat-soluble antioxidants (e.g., glutathione, ascorbate (vitamin C), α-tocopherol (vitamin E), and β-carotene); and endogenous antioxidants (e.g., albumin, bilirubin, and uric acid) [16,17]. Studies show that mitochondria of white adipose tissues, especially in obese individuals, are the main sites of ROS generation with participation of an increased expression of NDPH and decreased expression of antioxidant enzymes [18]. Oxidative damage to important cellular structures is one of the factors responsible for the development of obesity-related complications such as atherosclerosis, hypertension, insulin resistance, and type 2 diabetes [19,20].

Many markers are currently used to evaluate oxidative and antioxidative status in an individual. These include total oxidant capacity (TOC), total antioxidant capacity (TAC), oxidative

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stress index, which expresses the TOC/TAC ratio, and oxidized low-density lipoproteins (oxLDLs), which are lipid peroxidation metabolites [21–24]. Although there are many studies on oxidative stress in obese adults in the literature, to our knowledge there are no reports on this topic in the group of patients who were hospitalized during the beginning phase of cardiovascular rehabilitation program following myocardial infarction and were continuing with motor, diet, and pharmacological therapy. Therefore, the aim of this study was to assess the oxidative/antioxidative status and to investigate the correlation between redox markers and anthropometric parameters and body composition in adult patients after an episode of myocardial infarction and in those who did not suffer from a cardiovascular event previously. The first hypothesis was that people without a cardiovascular event in the past have higher levels of antioxidative markers and lower levels of oxidative ones. The second hypothesis was that the oxidative/antioxidative status is associated with obesity parameters, especially those describing the visceral distribution of adipose tissue.

2. Materials and Methods

2.1. Study design and population

A cross-sectional study was conducted during the period from August to December 2017 among 160 adults divided into two equal groups: study group and control group. Study group (SG) included patients who after suffering from a myocardial infarction were hospitalized during the early period of cardiac rehabilitation (up to 14 days after discharge from full revascularization) and who continued with physiotherapy, dietary, and pharmacological therapy in the "Uzdrowisko Nałęczów" S.A. Health Resort in Nałęczów and in the Railway Health Resort Hospital in Nałęczów (in eastern Poland). The study included patients from consecutive rehabilitation periods, which were held at 21- or 28-day intervals. All patients in this group were treated with primary percutaneous coronary intervention after the first myocardial infarction. The criteria for inclusion in the SG were as follows: age 40–65 years, condition after myocardial infarction, professionally active persons, and provide written consent to participate in the study. Exclusion criteria were as follows: renal failure, cancer, history of pulmonary or rheumatic diseases, and age under 40 years and over 65 years. Other exclusion criteria included factors that may influence oxidative status, such as infection (e.g., respiratory tract infections) and antioxidant vitamin intake. Research manuscripts reporting large datasets that are deposited in a publicly available database should specify where the data have been deposited and provide the relevant accession numbers. If the accession numbers have not yet been obtained at the time of submission, please state that they will be provided during review. They must be provided prior to publication.

Control group (CG) included professionally active adults without a cardiovascular event in the past but reporting for follow-up examinations to the occupational physician as part of periodic examinations. Respondents were recruited from the Provincial Center for Occupational Medicine of the Center for Prophylaxis and Therapy in Lublin (eastern Poland). The criteria for inclusion in the study were as follows: age between 40 and 65 years, no history of a cardiovascular event, low 10-year risk of a cardiovascular event (SCORE index < 5) [25], professional status (working person), no chronic diseases (renal failure, cancer, rheumatism, and lung diseases), no cardiovascular ailments that could suggest the existence of atherosclerotic CVD, no acceptance of preparations modifying the risk of atherosclerosis, and receiving no therapy for hypertension, pre-diabetes mellitus, and hypercholesterolemia. The exclusion criteria were as follows: active infection, intake of drugs or dietary supplements that may affect oxidative status (e.g., vitamins), and long-term use of fruit and vegetable diets only [26].

During the initial visit, all participants were investigated using an extensive questionnaire, interview, physical examination, and performing additional tests (anthropometric measurements), and the next day after the patient was prepared (12 hours of fasting), laboratory tests were carried out.

The research project received a positive opinion from the Bioethics Committee at the Medical University of Lublin (KE-0254/197/2017) and was conducted in accordance with the Helsinki

Declaration. All respondents were presented with the purpose of the study and then asked for written consent to participate in the study.

2.2. Anthropometric measurements

Anthropometric measurements of body height and weight were performed in all patients. Height was measured with the accuracy of 0.1 cm using an altimeter and body weight was measured without shoes and topwear using a platform scale with the accuracy of 0.1 kg. Then, the body mass index (BMI) index, defined as body weight in kilograms (kg) divided by the height in square meters (kg/m2), was calculated for all subjects [27]. Non-flexible measuring tape was used to measure the waist circumference (WC), between the lower edge of the ribbed arch and the upper comb of the hip bone, and the hip circumference (HC), at the level of the curve of the larger femur. Both measurements were taken in a standing position. Then, the ratios of waist to hip circumference (WHR) and waist to height circumference (WHtR) were calculated [28].

The percentage of adipose tissue content (FM [%]) was assessed using an electrical bioimpedance method with a body composition analyzer (OMRON Model BF306) according to the manufacturer's algorithm.

Visceral adiposity index (VAI) and body adiposity index (BAI) were calculated for all respondents on the basis of anthropometric measurements and biochemical results, but VAI was calculated separately for women and men. VAI for women = [WC/(36.58 + (1.89 × BMI))] × (TG × 0.81) × (1.52/HDL); VAI for men = [WC/(39.68 + (1.88 × BMI))] × (TG/1.03) × (1.31/HDL) [29], where TG represents triglycerides and HDL represents high-density lipoprotein. BAI = [HC (cm) / height (m) 1.5] – 18 [30,31].

2.3. Blood sample

Blood samples were taken from the elbow vein of fasting subjects in the morning (7:00–9:00 am) after an overnight rest in two tubes with clotting activator and separating agent (granules) and delivered to the laboratory within 1 hour. Samples were stored at 4°C until the blood sample was delivered to the laboratory. The plasma was separated by centrifugation at a rate of 3.000 rpm for 10 minutes. The serum from one tube was used for biochemical assays, while serum from the second sample was transferred to Eppendorf tubes immediately after centrifugation, then frozen at –80°C, and stored until the markers of oxidative/antioxidative status were determined.

Centrifuged serum from one of the tubes was used to determine the lipid profile (total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C)), serum glucose, and creatinine using standard laboratory methods. Low-density lipoprotein cholesterol was calculated from the Friedewald formula (when TG < 400 mg/dL), estimated glomerular filtration rate from the Cockcroft-Gault formula, and non-HDL from the non-HDL formula = TC [mg/dL] – HDL-C [mg/dL] [32].

2.4. Determination of oxidative/antioxidative status markers

Oxidative stress markers such as total oxidative/capacitive status (PerOx (TOS/TOC)) and total antioxidative status/capacity (ImAnOx (TAS/TAC)) were evaluated using photometric technique. Quantitative immunoenzymatic method was used to measure oxidized LDL (oxLDL). The determinations were performed by ELISA tests using the original reagents (Immun Diagnostik, Bensheim, Germany).

2.5. Statistical analysis

Continuous variables are summarized by means ± standard deviations or by median and interquartile range (q1–q3). Categorical data are presented as number and percentage (%). Comparison of variables of interest between clinical and control study groups was done using *t*-test or Mann–Whitney test for continuous variables and using chi-squared test for categorical variables. Due to skewness in the antioxidant values of oxLDL, PerOX values (right-skewed) were natural

logarithm transformed and the ImAnOx values (left-skewed) were squared. Associations between log oxLDL, log PerOx, and square of ImAnOx and anthropometric variables were assessed by Pearson correlations. Additionally series of liner regression models were performed to take into account the influence of gender (model I), age (model II), or smoking status (model III) on tested relationships. All analysis were performed in whole sample and in study and control group (supplementary file). Statistical analysis was performed using SPSS (version 25) software. A p-value < 0.05 was considered to be statistically significant.

3. Results

3.1. Characteristics of Participants

Table 1 presents the characteristics of the studied groups. The study involved 160 patients who are divided into two groups. The mean age in SG was 53.34 ± 4.74 years, and in CG it was 49.25 ± 6.23 years. No significant differences were observed in terms of gender, marital status, and family history of CVD in the studied groups ($p > 0.05$). Taking weight parameters into account, SG was characterized by significantly higher BMI, WHR, WHtR, and VAI values ($p < 0.05$) compared to those observed in CG.

Table 1. Baseline characteristics of the study population.

Variables	Study group (n = 80)	Control group (n = 80)	p
Demgraphic and clinical data:			
Age [years] [b]	53.34 ± 4.74	49.25 ± 6.23	< 0.001
Sex (Female *vs.* Male) [a]	22 (27.5) *vs.* 58 (72.5)	28 (35) *vs.* 52(65)	0.32
Marital status (free *vs.* in relationship) [a]	16 (20) *vs.* 64 (80)	11 (13.7) *vs.* 69 (86.3)	0.398
Clinical variables:			
Family history of CVD - on the mother's side [a]	46 (57.5)	42 (52.5)	0.634
Family history of CVD - on the father's side [a]	49 (61.3)	39 (48.8)	0.153
Diabetes [a]	19 (24)	1 (1,3)	< 0.001
Arterial hypertensions [a]	54 (68)	9 (11)	< 0.001
Smoking [a]	25 (31.25)	9 (11.25)	< 0.001
Anthropometric variables:			
BMI [kg/m^2] [b]	28.89 ± 4.91	26.64 ± 4.04	0.002
WC [cm] [b]	103.9 ± 12.48	93.36 ± 12.50	< 0.001
HC [cm] [b]	105.0 ± 10.83	102.9 ± 7.72	0.15
WHR [b]	0.99 ± 0.08	0.91 ± 0.09	< 0.001
WHtR [b]	0.60 ± 0.07	0.54 ± 0.07	< 0.001
FM [%] [b]	31.08 ±7.71	29.65 ± 7.05	0.22
VAI [b]	2.12 ± 1.56	1.06 ±0.7	<0.001
BAI [b]	28.63 ± 6.44	27.79 ± 4.73	0.35

Table 1. *Cont.*

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Variables	Study group (n = 80)	Control group (n = 80)	p
Biochemical parameters:			
Total cholesterol [mg/dL] [b]	147.81 ± 37	221.98 ± 44.2	< 0.001
Triglyceride [mg/dL] [c]	134.5 (103.25 - 174.35)	102.9 (73.4 - 141.15)	< 0.001
HDL-C [mg/dL] [b]	46.16 ± 11.50	64.05 ± 19.14	< 0.001
non-HDL [mg/dL] [b]	101.5 ± 34.31	157.9 ± 47.22	< 0,001
LDL-C [mg/dL] [b]	70.24 ± 25.86	134.81 ± 42.37	< 0.001
Glucose [mg/dL] [c]	102.5 (97.0-112.0)	102 (97.5-109.5)	0.78
Creatinine [mg/dL] [b]	0.85 ± 0.15	0.86 ± 0.18	0.97
eGFR [ml/min/1.73 m^2] [b]	93.5 ± 12.56	95.4 ± 13.33	0.35

Date are presented as: [a] n(%); [b] mean ± SD; [c] median (Q1-Q3).
BMI: body mass index; WC: waist circumference; HC: hip circumference; WHR: waist to hip ratio; WHtR: waist-to-height ratio; FM [%]: body fat percentage; VAI: visceral adiposity index; BAI: body adiposity index; HDL-C: high-density lipoprotein; LDL-C: low-density lipoprotein.

3.2. Oxidative/antioxidative status

Table 2 shows the oxidative/antioxidative status in the studied groups. There were no significant differences in PerOx levels between SG and CG patients, although the median value of this parameter was higher in CG and amounted to 718.01 μmol/L compared to SG, in which the median value was 699.44 μmol/L. Similarly, no significant differences were observed in the ImAnOx levels between the groups (p = 0.35). However, the higher median of this parameter was characteristic for SG (293.8 μmol/L) compared to CG (276.09 μmol/L). On the other hand, oxLDL was significantly higher in the group of patients without a cardiovascular event than in the group of patients after myocardial infarction (p = 0.02).

Figure 1 and Figure 2 illustrate a comparison of the oxidative / antioxidative status distribution in gender groups and depending on the smoking status of the entire sample. Gender significantly differentiated the overall oxidation / capacity (PerOx) status, higher values were found in women compared to men (p < 0.001). In other cases no significant differences were found.

Table 2. Oxidative/antioxidative status markers comparison of studied groups.

Variables	Study group (n = 80)	Control group (n = 80)	p
PerOx (TOS/TOC) [μmol/L]	699.44 (379.71 - 1152.36)	718.01 (298.35 - 1274.61)	0.77
ImAnOx (TAS/TAC) [μmol/L]	293.8 (246.52 - 317.92)	276.09 (233.76 - 333.33)	0.35
oxLDL [ng/mL]	54.25 (36.09 - 119.34)	75.91 (49.38 - 143.32)	0.02

PerOx (TOS/TOC): total oxidative status/capacity; ImAnOx (TAS/TAC): total antioxidative status/capacity; oxLDL: oxidized low-density lipoprotein.

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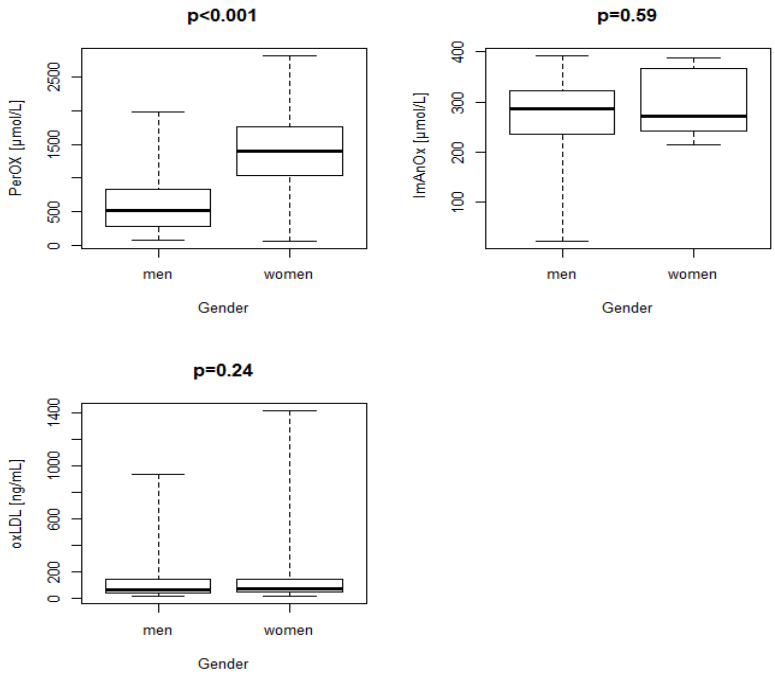
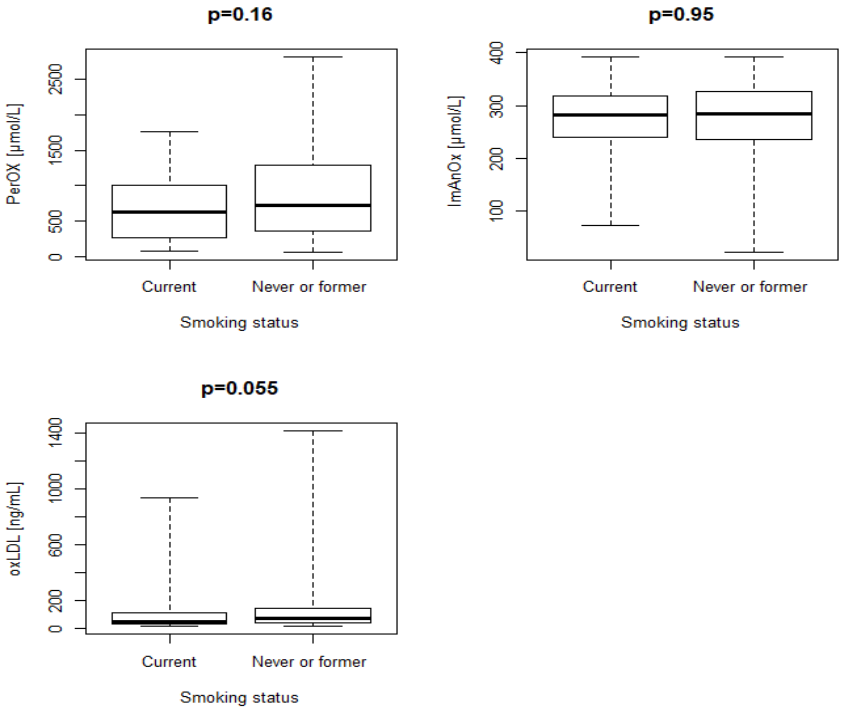


235

236 **Figure 1.** Comparison of the distribution of oxidation / antioxidative status parameters between men
237 and women (n = 160).
238 PerOx: total oxidative status/capacity; ImAnOx: total antioxidative status/capacity; oxLDL: oxidized
239 low-density lipoprotein.

240



241

242 **Figure 2.** Comparison of the distribution of oxidation/antioxidative status parameters between
243 current and never or former smokers (n = 160).
244 PerOx: total oxidative status/capacity; ImAnOx: total antioxidative status/capacity; oxLDL: oxidized
245 low-density lipoprotein.

3.3. Correlation between oxidative/antioxidative status and anthropometric measures

Table 3 shows the correlation between oxidative/antioxidative status and anthropometric factors. Significant positive correlations between PerOx and FM [%] (SG: r = 0.400, $p < 0.001$; CG: r = 0.337, $p = 0.002$) and BAI (SG: r = 0.335, $p = 0.002$; CG: r = 0.309, $p = 0.005$) were found in the two studied groups and among all the respondents (FM [%]: r = 0.365, $p < 0.001$; BAI: r = 0.316, $p < 0.001$). Significant negative correlation between PerOx and WHR (r = -0.281, $p = 0.01$) and VAI (r = -0.327, $p = 0.003$) was observed in CG and in the whole examined population (WHR: r = -0.206, $p = 0.009$; VAI: r = -0.214, $p = 0.006$). ImAnOx TAS/TAC significantly positively correlated with VAI (r = 0.391, $p < 0.001$) in SG, with FM [%] (r = 0.235, $p = 0.03$) in CG, and with these two parameters in the whole group (VAI: r = 0.18, $p = 0.02$; FM [%]: r = 0.154, $p = 0.05$). OxLDL negatively correlated with WHR (r = -0.243, $p = 0.03$) in CG and WHR (r = -0.210, $p = 0.009$) in the whole examined group. After adjustment for age or smoking status, the results were similar to those obtained in the simple linear regression models (Tables S1-S3). However, after adjustment for gender, the relationships between PerOx and WHR, FM [%] and BAI lost statistical significance.

Table 3. Correlation between oxidative/antioxidative status and anthropometric measures.

Variables	Log PerOx (TOS/TOC) [μmol/L]		ImAnOx (TAS/TAC) [μmol/L]		Log oxLDL [ng/mL]	
	r	p	r	p	r	p
Study group (n = 80)						
BMI	0.118	0.30	0.114	0.31	0.047	0.68
WHR	-0.148	0.19	0.176	0.117	-0.092	0.41
WHtR	0.180	0.11	0.079	0.48	0.064	0.57
FM [%]	0.400	< 0.001	0.039	0.73	0.105	0.35
VAI	-0.122	0.28	0.391	< 0.001	-0.038	0.74
BAI	0.335	0.002	-0.056	0.62	0.127	0.26
Control group (n = 80)						
BMI	-0.093	0.41	0.004	0.97	-0.216	0.06
WHR	-0.281	0.01	0.056	0.62	-0.243	0.03
WHtR	-0.082	0.47	0.120	0.30	-0.186	0.11
FM [%]	0.337	0.002	0.235	0.03	0.036	0.75
VAI	-0.327	0.003	-0.007	0.95	-0.071	0.54
BAI	0.309	0.005	0.152	0.184	0.037	0.75
Total (n = 160)						
BMI	0.015	0.85	0.071	0.38	-0.096	0.23
WHR	-0.206	0.009	0.128	0.10	-0.210	0.009
WHtR	0.04	0.61	0.126	0.116	-0.098	0.22
FM [%]	0.365	< 0.001	0.154	0.05	0.059	0.46
VAI	-0.214	0.006	0.18	0.02	-0.087	0.28
BAI	0.316	< 0.001	0.055	0.49	0.08	0.32

BMI: body mass index; WHR: waist to hip ratio; WHtR: waist-to-height ratio; FM [%]: body fat percentage; VAI: visceral adiposity index; BAI: body adiposity index; PerOx (TOS/TOC): total oxidative status/capacity; ImAnOx (TAS/TAC): total antioxidative status/capacity; oxLDL: oxidized low-density lipoprotein.

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4. Discussion

The relationship between oxidative stress and CVD is of immense interest to many researchers. It was demonstrated that both excessive oxidative stress and inadequate antioxidative defense mechanisms may cause an early onset of CVD [33]. Increased oxidative stress markers act in synergy with standard risk factors for CVDs [34,35]. In this cross-sectional study, we evaluated the oxidative/antioxidative status in parallel groups and examined the correlation between redox markers and anthropometric parameters and body composition in the group of adult patients undergoing cardiac rehabilitation after suffering from myocardial infarction and in individuals who had not suffered from a cardiovascular event in the past. This is probably the first study to evaluate the oxidative/antioxidative status of a group of people who enrolled in a cardiovascular rehabilitation program following myocardial infarction and in those without a cardiovascular event, during the subclinical development of atherosclerosis, and to identify which patients require primary prevention (CG) or secondary prevention (SG) based on the risk of cardiovascular complications. The results of our study did not confirm the first hypothesis. The markers of oxidative/antioxidative status were better indicated in SG than in CG. The second hypothesis was confirmed because our study proved that visceral fat distribution is correlated with oxidative/antioxidative status, so management should place particular emphasis on weight reduction.

Our study showed that lipid peroxidation (oxLDL) was much stronger in CG than in SG patients. The result we obtained was completely different from the results obtained by Dominguez-Rodriguez et al. [36], who evaluated nighttime oxLDL and melatonin levels in patients with acute coronary syndrome (ACS) and healthy subjects without symptomatic atherosclerosis. In this study, the group of patients with ACS had higher levels of oxLDL and lower levels of melatonin than CG patients. However, in the Renko et al.'s [37] study conducted in a group of 120 men after myocardial infarction and 250 men in the CG, no significant differences between groups were found in the oxLDL level. The results of our study were obtained in a group of patients who after suffering from myocardial infarction were receiving early cardiological rehabilitation, including physiotherapy, pharmacotherapy, and dietary treatment. As the literature indicates, the occurrence of myocardial infarction leads to the modification of lifestyle-related behaviors to a more pro-healthy one, especially in the context of dietary changes [38]. The change of the diet to the one containing less fat resulted in a decrease in oxLDL levels in the group consisting of obese women, which was demonstrated by Elizabeth et al. [39] in their study, as well as in the patients who participate regularly in Nordic walking, in the study by Cebula et al. [40]. Moreover, higher oxLDL levels in CG in our study may be associated with higher levels of LDL-C in this group, because the processes involved in the modification of this cholesterol fraction play a key role in the formation of atherosclerotic plaque [41]. The above arguments may also influence the results obtained with respect to other markers of oxidative status (PerOX), which was lower in SG, and antioxidative status (ImAnOx), which was higher in CG, although these differences were not statistically significant ($p > 0.05$). In our study, CG is characterized by higher blood lipid indices compared to SG (TC, $p < 0.001$; LDL-C, $p < 0.001$; and non-HDL, $p < 0.001$). The available literature data indicate a close correlation between the development of atherosclerotic plaque, determined by the thickness of the intima-media complex, and the concentration of not only TC but also its individual lipid fractions in blood [42–45]. Selection of respondents for CG was conditioned by non-administration of preparations modifying the risk of atherosclerosis; therefore, it can be assumed that high lipid levels correlate with the development of atherosclerotic plaque, and the changes in vascular endothelium are reflected in oxidative/antioxidative disorders.

Drugs taken by the patient are very important in determining the level of oxidative stress. The respondents after myocardial infarction were staying in the Health Resort Hospital and each of the respondents took their medicines systematically. Some of the drugs are known to influence the level of oxidative stress. Aspirin, statins, angiotensin converting enzyme II (Ang II) inhibitor, and metformin are commonly used in the secondary prevention of cardiovascular events and treatment of concomitant diseases; they also exhibit many pleiotropic effects [46]. The Paseban et al.'s [47]

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study showed that the combined use of the above-mentioned drugs enhances their antioxidant effect. Aspirin has an antioxidant effect by reducing the production of free radicals such as peroxide and prevents a decrease in the activity of antioxidant enzymes (catalase and peroxide dismutase) [48]. Statins, due to their antioxidant activity by inhibition of NAD(P)H oxidase and active exchange of free radicals [49–51], reduce chronic inflammation [52] and thus reduce oxidative stress [53]. Ang II inhibitor may selectively reduce Ang II, endothelin, and oxidative stress levels, which may potentially play a role in the lowering of blood pressure [54]. Moreover, in our sample, 24% of SG patients are diabetics. Metformin is the first hypoglycemic drug used in the treatment of patients with type 2 diabetes, and it has been shown to reduce ROS by enhancing the activity of antioxidant enzymes [55].

Studying the relationship between gender and oxidative/antioxidant status is vital as oxidative stress is a factor in the development of numerous diseases, including cardiovascular diseases, and at the same time, these diseases occur differently in men and women. It was proved that oxidative stress was lower in male rats than in females [56]. Ide et al. [57] showed that biomarkers of oxidative stress in vivo were higher in young men than in women of the same age. In other studies, it was observed that ROS production was higher in blood vessel cells in men than in women [58], and women were found to have the greater antioxidant potential [59]. Other studies indicate that there is a difference in the expression and/or activity of antioxidant enzymes between men and women. These enzymes are present in various body tissues. With regard to SOD, there is no uniform consensus on gender differences, although it is suggested that there may be variances in different tissues. Chen et al. [60] showed that the level of SOD activity in brain tissue and lungs was higher in female mice, but there were no significant differences in the level of SOD activity between females and males in the kidney and heart. However, Barp et al. [56] established that female rats had a higher level of SOD activity in the heart than males. Interestingly, they also found that after castration, the level of SOD activity in both male and female rats was significantly reduced compared to the control group. The results of the cited researchers indicate that there may be a relationship between sex hormones and the level of SOD activity. However, some studies have not shown differences in the level of SOD activity between men and women; therefore, there are some differences regarding the association of SOD activity and gender [57, 61]. Chan et al. [60] revealed that catalase activity in both female and male mice was the same in the brain, lungs, and heart, but higher in females in a kidney. However, some studies did not demonstrate differences in the level of catalase activity between men and women [56, 57, 62]. Thus, the studies cited above indicate that gender and sex hormones do not affect catalase activity, and thus, the degradation of hydrogen peroxide [63]. Several studies have shown that GPx activity was lower in women than in men [56, 57, 60], although there was no significant change in GPx levels after castration, suggesting that sex hormones may not affect GPx [56]. The fact that GPx levels were lower in women seems counterintuitive because women are thought to be less prone to oxidative stress than men. This observation suggests that women possess other mechanisms to protect themselves against oxidative stress. Although there may be some differences in the level of antioxidant enzyme activity between men and women, as discussed earlier, the difference in antioxidant properties is probably due to estrogen [63]. This sex hormone acts as an antioxidant, scavenging free radicals due to the presence of a phenolic hydroxyl group [56]. In the presented research, the overall oxidation/capacitance status (PerOx) was higher in women than in men. The explanations for this result can be seen in the menopausal or postmenopausal period in which the women were examined, which reduced the concentration of estrogens in the studied group.

Obesity is considered to be an important risk factor leading to the development of many diseases such as ischemic heart disease, diabetes, hypertension, dyslipidemia, stroke, and some types of cancer [64,65]. This metabolic disorder is associated with an increased ROS production and oxidative stress formation. Increased ROS production in obese individuals is associated with excessive supply of macronutrients in diet, mitochondrial dysfunction, excessive ROS production at the endoplasmic reticulum level, and inflammatory response [66,67]. Obesity is one of the factors leading to oxidative stress, which in turn leads to atherosclerosis of vessels and, consequently, may

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lead to myocardial infarction. Amirkhizi et al. [68] conducted a study on obese women and found that obesity, even in the absence of smoking, diabetes, kidney, and liver diseases, may reduce protective antioxidant mechanisms by increasing systemic oxidative stress.

In our study, anthropometric and physiological measurements (WHR, FM [%], VAI, and BAI) significantly correlated with the oxidative/antioxidative status in SG and CG patients, as well as in the entire sample. Moreover, we discovered several significant correlations between VAI and BAI and oxidative/antioxidative status in both groups. In our study, the oxidative/antioxidative status was more often correlated with FM%, VAI, and BAI than with BMI. Although BMI is used to measure overweight and obesity, it does not take into account factors such as body size and adipose tissue distribution. Studies suggest that abdominal obesity is more strongly associated with chronic diseases [69,70], because visceral fat secretes several metabolites that cause chronic diseases [71,72]. Chrysohoou et al. [73] concluded in their study that the total oxidative capacity (TAC) was significantly correlated with the central obesity index rather than with obesity. Visceral fat accumulation (measured by computed tomography), as a factor associated with enhanced oxidative state, was also demonstrated by Araki et al. [74]. The importance of adipose tissue distribution in the context of oxidative stress in obesity was demonstrated by other authors who found a correlation between anthropometric parameters (WC and BMI) and the level of oxidative stress activation [75,76].

4.1. Limitations

Our study has a few limitations. First, it is a cross-sectional study, so neither temporality nor causality can be established. Second is the inclusion of a relatively small number of patients from a single center, especially with regard to patients qualified to be included in SG. The third limitation of our study is the use of bioelectrical impedance analysis (BIA), which is an indirect method for the evaluation of body composition. However, comparative studies have shown significant correlations between BIA data and body composition measured by densitometry (dual-energy X-ray absorptiometry (DXA)), which is the golden standard for this type of analysis [77]. Unfortunately, DXA is associated with exposure to X-rays, which limits the regular use of this method. The fourth limitation of our study was the non-inclusion of drugs taken by patients in the analysis of oxidative stress levels in particular groups, although the main aim of the study was to assess the parameters related to obesity and oxidative/antioxidative status, but these drugs may have influenced the results of the study.

5. Conclusions

To sum up, our study shows that total oxidative/antioxidative status is related to the adipose tissue content and skewness BAI of the subjects, but it was observed that it correlates more frequently with the visceral distribution of adipose tissue. Given the significant association of visceral fat distribution with oxidative/antioxidative status, further studies are needed to investigate the impact of fat distribution on the risk of cardiometabolic diseases, especially in conjunction with other common cardiovascular risk factors.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, **Table S1:** Relationship between oxidative/antioxidative status and anthropometric measures in study group, **Table S2:** Relationship between oxidative/antioxidative status and anthropometric measures in control group: **Table S3:** Relationship between oxidative/antioxidative status and anthropometric measures in all participants.

Author Contributions: G.J.N. and B.Ś. developed the concept of the study. G.J.N. and M.P. analyzed the data and contributed to its interpretation. G.J.N. interpreted the data and wrote the original draft. G.J.N., B.Ś. and A.P. were involved in writing, reviewing and editing the manuscript. G.J.N., M. C-K. and E R.-D. were responsible for funding acquisition and supervision. All authors were involved in critically revising the manuscript, and have given their approval to the manuscript submitted.

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